A Premier Quality Homebrew Stereo Amplifier

The Rebirth of the Classic Williamson

Part One

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Some time ago I added a Compact Disc player to my 20 year old home audio system and it wasn't long before this new program source brought to light a number of deficiencies in my Pioneer integrated amplifier. Not only did it not sound as good as I thought it should, but its controls and switches were beginning to show the effects of years of wear. Having decided its eventual replacement was in order, I began reading a number of audio magazines in an effort to familiarize myself with the current state of audio technology. I felt like old Rip Van Winkle while I paid for some of my college back in the mid-70s by working at a stereo store as a repair tech. I hadn't paid any attention to the subject in the subsequent 20 years.

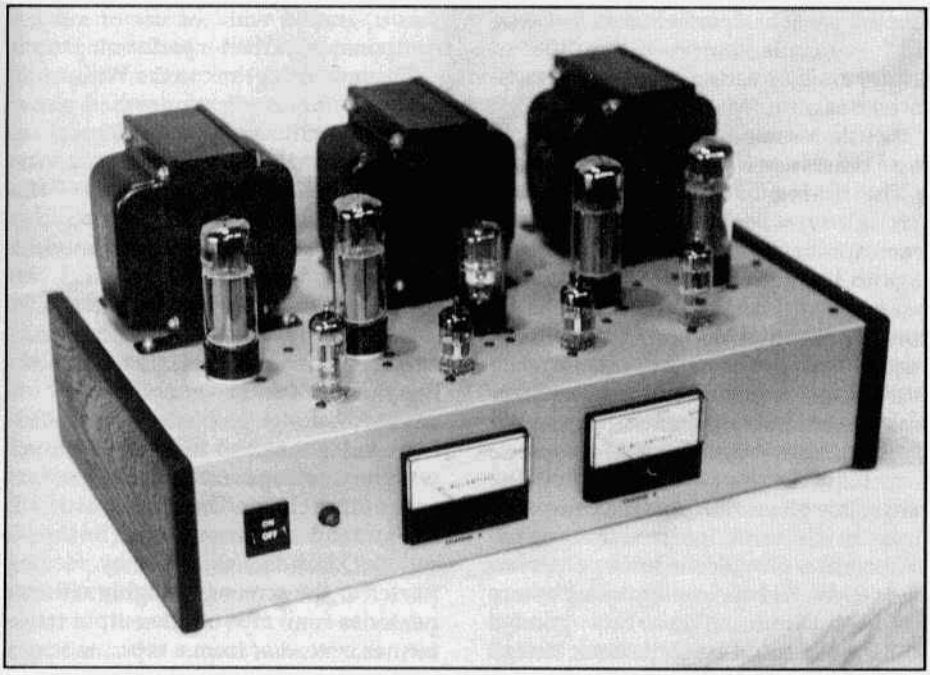
A surprising fact came to light in short order. Many of the currently manufactured top line amplifiers in the $1000+ price range, along with preamps and even CD decks use vacuum tube technology. Actually, I was astonished, in a way. Imagine opening up a new *QST* and finding companies have brought back their tube products of years past. "...The NEW Collins 75A-4C. . . Johnson announces the return of the Viking Ranger! . . ." Audio magazine reports at least 50 firms world wide are now making vacuum tube amplifiers; there's even one firm making a hollow state car stereo! There appear to be several reasons for this resurgence of vacuum tube technology. First is the feeling of many discriminating audiophiles that tube amplifiers compliment the sound of today's digital program sources in a positive way; that the sound is integrated in a wholly different manner than in transistorized units. Another reason appears to be that consumers of top end audio are finally getting smart, realizing that one can pay top dollar for an imported top line audio system but all the extra money generally buys is overpriced mediocrity: one gets more fluff, cosmetics, bells and whistles and the same basic electronic design of a less expensive unit. (Unfortunately, the same situation is true in the area of today's ham gear.) The last reason for the interest in hollow state is the snob appeal of a gleaming chassis with a number of large glowing bottles on top. What could possibly look more purposeful and powerful than something like a MacIntosh 240 or modern day equivalent? There is and will always be a magic and appeal to those large, heavy and hot behemoths that glow in the dark.

My wife eventually made the final decision for me, reminding me that I'd spent countless hours over the years homebrewing ham gear; why not build something for once that the whole family could enjoy?

The Design

There have been incredible numbers of amplifier designs published over the past few decades in varying degrees of performance and complexity. I looked over many of these as well as the designs of the well known commercially manufactured amplifiers of the 1950s. The circuit I kept coming back to was one that may have been built in larger numbers than any other - the "Williamson" amplifier that was first described in *Wireless World* in 1947. I found dozens of references to this amplifier in many publications of the '50's and many modifications, criticisims and upgrades. It was most likely the Williamson design that kicked off the "Hi-Fi" mania that swept the electronic hobbyist world in the '50's.

To understand what a breakthrough



Front/top view of the homebrew amp.

this amplifier was we need to get a little historical perspective on the subject. D.T.N. (Theo) Williamson was a young man in his 20's who worked in the English laboratories of the Marconi-Osram company as a tube development engineer. Sometime during the mid-'40's he became intrigued with the idea of developing an essentially distortionless amplifier and he spent many hours experimenting with different designs. He eventually came to several conclusions during this development. First, and most important, was how crucial the output transformer was in his overall design. And his design was simple in structure, containing no new technology. The realization of extremely high levels of performance in his design was almost entirely dependent on using a high level of inverse feedback (about 20 dB) around the entire amplifier, and included within the loop was the output transformer. Most other feedback designs of the '30's and '40's excluded the output transformer from the feedback loop; the feedback signal was commonly derived from the plate of one of the output tubes. The reason for this was that at the extremes of the audio range a large degree of phase shift occurs both in the output transformer and in an amplifier's circuitry, and this causes the applied out of phase feedback to be more in-phase and create instability and oscillations at those frequency extremes. Williamson's answer was to design an output transformer of exceedingly high specifications and to minimize the number of or eliminate cathode bypass and coupling capacitors in the circuitry. The basic structure of his resulting amplifier consisted of an all-triode design of four stages: single-ended voltage amp DC coupled to a phase splitter, followed by proven and reliable push-pull driver and output stages. A very simple design resulted with a number of subtle refinements that achieved tight control of phase shift over many octaves of frequency. The 22 year old Williamson had designed an

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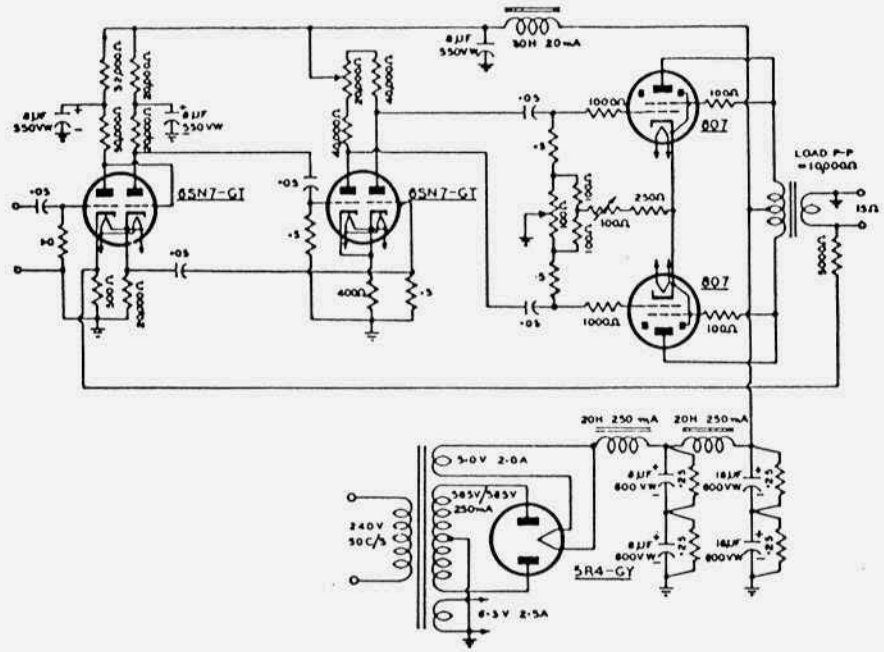
amplifier that had performance far better than any contemporary of the '40's, in large part by treating the output transformer as an integral part of the design rather than something merely 'hung on' to an otherwise well designed circuit.

The timing of Williamson's breakthrough was perfect - the world was transitioning from 78 RPM disc recordings to the new media of microgroove records, FM broadcast and magnetic recording. Even when using a 78 RPM record as a program source, the Williamson amplifier had a sound that was demonstrably better than any other then available. With a frequency response essentially flat from 10 Hz to the 100 Khz range, low phase shift, and distortion figures in the tenth percent range, the Williamson provides a level of performance hard to beat even by today's standards. I wondered just how good a Williamson could be if the basic design was upgraded with the use of modern components and better performing tubes.

The only drawback to the Williamson design for my application was its power output specification. At best, a pair of triode connected 807s can generate some 20 watts. OK in those days past of efficient horn speakers and monster bass reflex enclosures, but not adequate with the use of todays more compact high performance/low efficiency speakers.

In the early '50's, an American audio engineer named David Hafler was thinking along much the same lines. His answer to the design problem of great sounding triodes that had low power output was the development of the "Ultra Linear" output circuit. The concept of the UL design (and similar ones such as the so-called Q.U.A.D.) was that by feeding power to the screens of highly efficient pentodes from taps on the output transformer instead of from a separate screen



Schematic of the original Williamson amplifier, ca. 1947.

supply one could achieve a "semi-triode" form of operation. With taps placed on the output transformer's primary approximately halfway between the center B+ connection and end plate connections one could almost double the output generated by a strictly triode connected pentode and still retain a low order of distortion.

It wasn't long before both homebrewers and audio equipment manufacturers of the '50's figured out that the Hafler circuit made an ideal way to "juice up" the output of the original Williamson design, and several such designs were published. With pencil in hand, I decided that the Williamson/Hafler design was the one I was going to pursue - the specs were just what I was looking for.

Output Transformers

As I previously mentioned, the key piece of the Williamson, or for that matter, any other high performance audio amplifier is the output transformer. The best ones of the 1950's were never inexpensive, but at least there were a multitude of more or less off-the-shelf models available made by manufacturers such as Stancor, Peerless, UTC, Dynaco and others. There are far fewer manufacturers of suitable transformers today and yes, they are still expensive, but not more so in inflation adjusted dollars. Hooking up with a good transformer manufacturer today is a matter of finding their ads in magazines that cater to the market. Periodicals such as *Glass Audio*, *Sound Practices* and the nationally distributed *Audio* all contain ads by small specialty transformer shops. Several are here in the states, but a well known line is made in Japan under the brand name "Tango" and are sold by a U.S. distributor. Remember, it's important that one develop a high performance amplifier around a transformer as Williamson figured out nearly 50 years ago, so getting your hands on the iron first is a prerequisite. I can't overemphasize the importance of buying the best iron you can afford!

Through an ad in *Sound Practices* I became aware of a builder of hand-crafted transformers, named Mike LaFevre, who operates under the name of Magnequest in Philadelphia. Mike has several models of audio output transformers available for a number of applications. He has been a long time student of the craft having over the years obtained the original manufacturing prints from legendary manufacturers of heavy iron such as Peerless. He has learned the science from the guys who used to be in the business in years past, much as apprentices in the crafts used to. Mike's transformers use some of the more modern advances in materials such as Nomex insulation (of fire suit fame) and teflon lead wires, and are built with painstaking attention. After discussing my needs with him on the phone I ordered a pair of his MQ-431 models with a screen tap option. My billfold became lighter to the tune of some $300, and I had to wait several months for delivery, but the transformers eventually did arrive and I was able to start breadboarding. As a point of interest, Antique Electronic Supply carries a line of much less expensive high fidelity output transformers made by Hammond Manufacturing of Buffalo, NY. I obtained a spec sheet on their 100 watt rated model 1650R; it looked pretty good on paper and might be well worth considering. The important specifications in any transformer for the Williamson amplifier are the value of primary inductance and the primary to secondary leakage inductance (Williamson specified 100 Hys minimum for the former and 50 mh maximum for the latter). As with any transformer used in a push-pull amplifier, balance is important as well as the power rating - don't skimp on the iron!

If the transformer you choose has a greater primary inductance than the one I used, the values of the coupling capacitors may be increased proportionately. This is a place where cut and try on the workbench may be called for.

One final note on the subject of feed-

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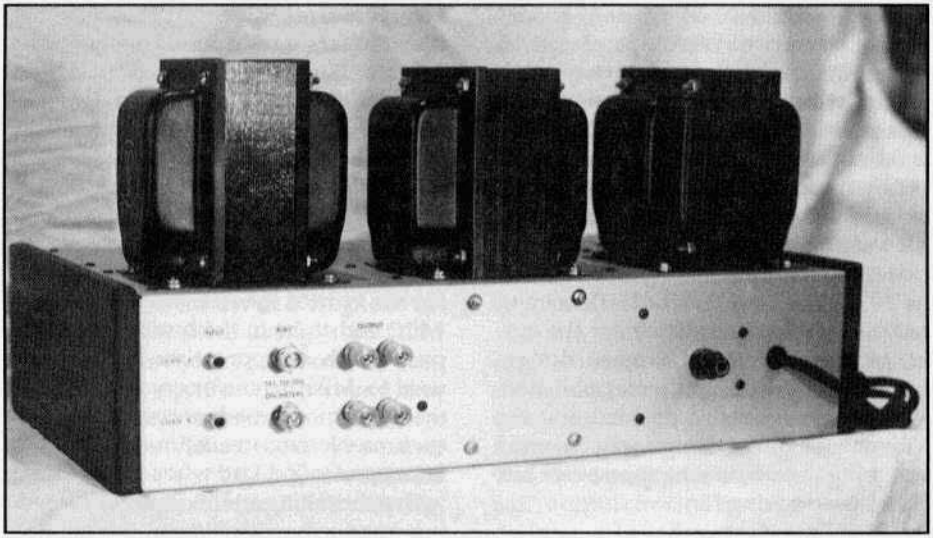

Rear view showing input/output connectors and balance controls.

back and the output transformer. If your completed circuit oscillates or motorboats, your first action should be to reverse the polarity of the transformer; swap the plate and screen leads from one set of output tubes to the other. As we all know, a circuit using in-phase feedback is called an oscillator!

CHASSIS

I could almost write an entire article on just the subject of selecting and finishing a chassis for a project of this type. It seemed pretty clear to me that considering the weight of all the iron [about35# worth] that was to be bolted on it, a steel chassis was going to be the only way to go. The other thing going in favor of steel was my plans to have the entire chassis nickel or chrome plated; this was, after all, a project destined for use in the living room. I went through all my parts catalogs and even called Bud only to find out that the standard steel chassis had apparently gone the way of platform shoes and disco, and at about the same time-Darn! 20 years too late again! After many more checks I made a number of breakthroughs at about the same time. Yes, one company still does make a line of standard steel chassis. They are Hammond, of Buffalo, NY- yes, the same folks that make the previously mentioned transformers. Not only do they still make the chassis, but also the matching perforated 'amplifier' covers that were de rigeur back in the '50's. But better yet, I made a few breakthroughs in the world of aluminum. It turns out that an old company in the business, Premier Metal Products of New York City makes a line of 11"x17" chassis that are substantially thicker and heftier than those made by Bud and others. Due to a different style of assembly, they also have flat sides without any overlaps and have reinforcing gussets welded into the bottom corners. I highly recommend these chassis for any homebrew projects that have a lot of weighty components. The only problem in dealing with Premier is that they have a $50 minimum factory order, so I had to order two chassis and bottom covers. And, oddly enough, their Bronx, NY headquarters won't accept telephone credit card orders, but their Los Angeles branch will.

There are far more options available for finishing aluminum than there ever were before. Many plating shops now have the ability to plate aluminum with nickel,

which can be left as is, or plated over with other metal such as chrome. Yes, one can have a chromed aluminum chassis, or for that matter, I always thought gold plating would be awfully nice! Regardless of whatever finish you choose, surface preparation is very important. Defects such as scratches will be painfully obvious on a finished product. I took the advice of a metal shop and laid out my parts on the blank chassis and did as much drilling and other metalwork as possible prior to sending it out. You run the risk of chipping off plating when drilling on it. What finish did I choose? I took my punched and drilled chassis to a metal finishing shop, and for $12 they buffed it out and put a grained finish on all the surfaces with the use of a machine that employs a giant "Scotchbrite" belt. I then sent it to a plating shop and had it hard clearcoat anodized. The appearance of the finished product is truly professional. Some time after I had completed final assembly, I went to a dealer that specialized in sales of small amounts of hardwoods to the carpentry trade and picked out a small piece of a type of African hardwood called 'Wenge'. This type of wood is very heavy, hard and has more of a natural black color to it than most others. I milled out and sanded a couple of pieces to the correct size, applied a clear oil finish, and attached them to the chassis with a couple of small brass woodscrews from the inside and a small amount of "Liquid Nails" construction adhesive. The completed amplifier looks better than many commercially made units, I think. **ER**

Editor's Note:

Parts two and three of this article will appear in the next two issues.

Mix the Old and the New

I thought you might be interested in hearing about an effort to mix the old and the new... namely tube type gear and international computer networks. About a year ago some of us who have access to the Internet (a worldwide computer network linking business, industry, the military and colleges) were engaged in a discussion of DX-100s on the rec. radio. amateur newsgroup. After more people joined in the discussion, Jim, KM6HK, (who has provided some of the photographs used in ER) created a mailing list where those of us of the hollow state persuasion could send a note, and have it relayed to all others in the group. Early members included: Mick, KD4CPL; Jim, WA7LDU; KM6HK and a few others.

Although Jim had to relinguish the role of list maintainer, Paul, N1AAC stepped in and is maintaining the group, which has now grown to almost 100 'subscribers'. Discussions have included crystal grinding, restoration techniques, the aforementioned DX-100 history and other topics. There are quite a few members with particular expertise, including Chuck, WA7ZZE, whose Heath articles have graced ER recently.

We welcome anyone with Internet access to join us by sending a note to Paul at: **owner-boatanchors@gnu.ai.mit.edu**

Make sure to include your return internet address in the text of your message to make Paul's job easier.

Computers and tube gear CAN go together! **John, wb5oau, brewer@anarky.enet.dec.com**

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The Rebirth of the Classic Williamson

Part Two

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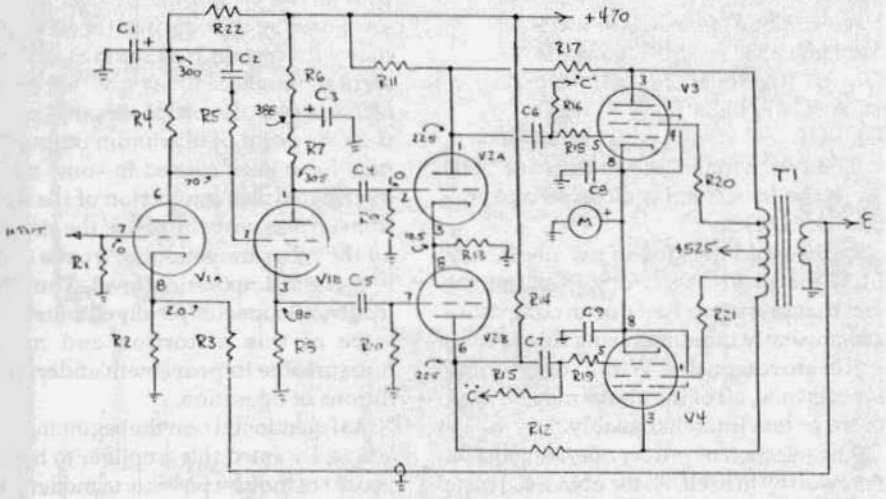
Circuit Design

This is an area where I utilized both my own observations and published articles on the Williamson from the '50's. My process was to breadboard parts of the circuit and make measurements regarding behavior at different signal levels. Notes on each circuit revision were kept in a notebook for reference and comparison. The test equipment I used was an Eico 378 audio generator (a better performer than my old HP 200CD), an HP 331 distortion analyzer and a Tektronix 547 scope with 1A2 dual-trace preamp.

Over the years, some criticisms and modifications of the basic Williamson design have been published. The most interesting article I found was one that appeared in Audio Engineering of August, 1952. [Note: This magazine was the renamed Radio magazine of an earlier era; it still exists and is now called Audio]. The author of the 1952 article suggests a number of improvements that I took into consideration in my own prototype. The first changes involved replacing the original 6SN7 preamp and driver tubes with some better performers in terms of hum, noise and output voltage capability. That's not to say there's anything wrong with the original 6SN7 design; we're talking refinements here. I spent a number of evenings looking at tube data sheets and my own selections were the use of the 6DJ8/6922 as a preamp/phase splitter and the use of a 12BH7 as the push-pull driver stage. My logic behind use of the 6DJ8 was that it's a low noise tube, originally designed as a VHF amplifier/mixer. Its other advantages are that is uses a rigid frame grid construction, which would tend to minimize microphonics, and it doesn't have as high an amplification factor as the more commonly used 12AY7, hence more bias voltage can be used, allowing the tube to handle larger input signals before running into grid current. The 12BH7 was chosen for its low plate resistance, high plate voltage rating, easy availability and once again, low amplification factor and subsequent ability to handle large signal voltages. In most class A voltage amplifiers, the total harmonic distortion is directly proportional to the output voltage being delivered as a percentage of maximum output capability. In other words, big output voltage capability=lower distortion. On my bench, the 6DJ8-12BH7 combination was able to deliver over 250 volts peak to peak output voltage at less than 3% THD+noise. Since the maximum peak output voltage it would ever need to deliver would be on the order of 45 volts, we're talking one heck of a good driver. I measured the THD at about .35% at 45 volts P-P output on the bench.

Other notes on the preamp/driver stages. According to my Amperex tube handbook, both triode sections of the 6DJ8 do not have the same heater-to-cathode voltage rating. Section 2 (pins 1-2-3) has the greater rating. This is apparently due to its original design for use in cascade VHF amplifiers. With regard to the 12BH7, I plotted a loadline and selected a nominal value of 950 ohms for a cathode resistor as the schematic shows. It is, however, possible to make a noticeable reduction in the complete amplifier's THD by reducing this resistor to a value of around 750 ohms.

The downside to doing this is that certain brands of tubes get slightly unstable and create a small ringing type of oscillation evident on portions of low frequency (20 HZ or so) waveforms. Plate dissipation is also increased. I mention this as a



Schematic of the amplifier, one channel shown.

Parts List - Williamson Amp (one channel)

C1, C3 - 10 uF/400-V electrolytic
C2 - 820 uf/300-V mica or polystyrene
C4, C5 - .01 uF/500-V or better Vitamin Q or polypropylene, matched to 1% or better.
C6, C7 - .25 uF/500-V or better Vitamin Q or polypropylene, matched to 1% or better.
C8, C9 - .1 uF/100-V tubular

Note: All resistors are metal film or metal oxide film unless otherwise noted. All resistors of like values are matched to within .5% using a DVM.
R1- 47K, 1/2-W
R2 - 470, 1/2-W
R3 - 3.92K (for 8 ohm), 2.4K (for 4 ohm), value is 1200 divided by the output impedance (feedback resistor).
R4 - 47K, 3-W
R5 - 4.7K, 1/2-W
R6-R8 - 22K, 2-W
R9-R10 - 220K, 1/2-W
R11,12,14,17 - 100K, 3-W
R13 - 950, 1/2-W
R15,16 - 100K, 1/2-W
R18,19 - 4.7K, 1/2-W
R20,21 - 1K, 2-W
R22 - 33K, 3-W

M - 300 mA DC panel meter
T1 - output transformer, screen taps at 40-50%
V1 - 6DT8/6922
V2 - 12BH7A
V3 - 6CA7/EL34, 6550 or 6L6GC

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point of interest; the complete amplifier has such low distortion that one would never hear the improvement such tweaking will make.

The selection of output tubes was an interesting project in itself. Many types were tested in my breadboard circuit with a number of different plate voltages. As I have a couple of pre-school toddlers around the house, tubes with plate caps were tested but never seriously considered. There were two bottom line issues involved in the decision making process, those of performance and availability (price!). Under identical conditions of 450 plate volts, and using manufacturer's recommended bias, I measured the output power generated at the visual onset of clipping as viewed on the scope.

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Sylvania 5881,	50 watts
Sovtek (USSR) 6L6GC	36 watts
Sylvania 6550	66 watts
GE 1614 (metal 6L6)	41 watts
RCA 6CA7/EL34	50 watts
GE 8417	68 watts

The two winners in the battle of THD were the 6CA7 and a close second, the Sovtek 6L6GC.

In the end I decided to use the 6CA7/EL34 for its great performance and the fact that perhaps a half dozen companies are presently manufacturing this tube so prices are reasonable. With a socket wired for this tube, all of the above may be used more or less interchangeably.

The selection of proper operating bias is noteworthy in itself. At the above 450 plate volts, the 6CA7s produce the overall lowest distortion at an idle current of about 110 mA per pair. My finished amplifier, on the other hand, has a plate voltage of near 530 volts. At this higher plate voltage, the best overall bias level as tested for THD was around 70 mA. An attempt to use anything over 100 mA surprisingly caused higher distortion, and the tubes were running awfully warm near their maximum rated dissipation ratings. Idle current on the higher side made for lower THD at lower levels; conversely, lower idling plate current made for lower distortion at maximum output. A current near 50 mA caused a profound dip in THD at full output but an increase at the 5 to 10 watt level. In general, it seems, idle current should be inversely proportional to applied plate voltage, approaching a little over 100 mA if plate voltage is much less than 500.

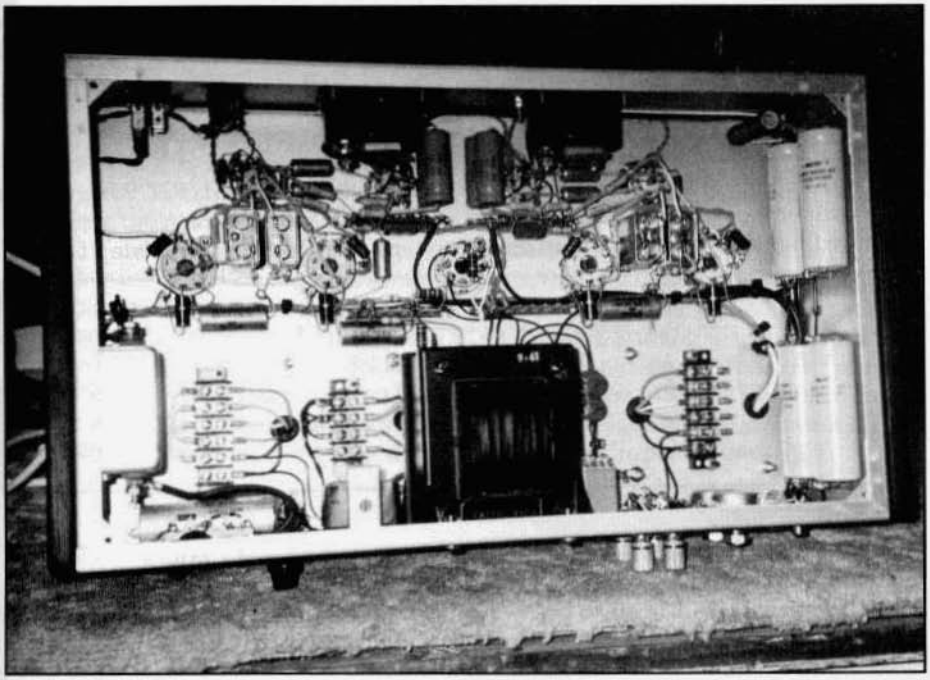
A final note on bias - if one adds a 10 to 22 ohm, 2 watt resistor in series with the common cathode connection and ground of the 6CA7s, a measurable decrease in distortion can be observed with some types and brands of tubes. Once again, probably never audible but observeable on test equipment.

I made another minor change to the original Williamson design that I haven't seen published elsewhere. R12 and R17 provide an additional inverse feedback loop around the output tubes. I found that with certain bias settings, and with certain brands of tubes, a visual amount of crossover distortion became evident near the point of maximum output. This may have been caused in some manner by the complex interaction of the output transformer with the rest of the circuit, or by the tubes transitioning from a class A to a class B operating level. The added feedback loops completely eliminated any trace of this distortion and made a measureable improvement under all conditions of operation.

As I mentioned near the beginning of this article, I wanted this amplifier to have the benefit of the best possible in modern components (within reason... I've seen custom hand rolled silver foil capacitors go for more than $1,000-each). All resistors other than the bleeders are metal film or metal oxide types. These resistors are reasonably priced from sources such as Digi-Key in Minnesota, and they have superb specifications in areas such as stability, temperature drift, overload capability and voltage coefficient. They are available in ratings up to three watts. Bear in mind that under-chassis temperatures on a piece of equipment such as this can get outrageous; it's perhaps best to operate resistors with a large power derating factor - use ones two or three times larger than actually needed. The wattage ratings shown in the parts list reflect this conservative design philosophy.

As this is a push-pull amplifier, balance is important. I purchased twice as many resistors as called for and matched pairs of like value with the use of a DVM. The real crucial ones are R 7, 8, 11, 12, 14 and 17, but try to match all of them if possible.

Capacitors are another subject area one could write an entire article on. There are objective and subjective reasons to use different types or not to; I chose to go with the prevailing opinions in the audio press on types. The coupling capacitors in the signal path are Sprague "Vitamin Q" types, which



Underside of the chassis.

most hams with any self respect should have available in their junk boxes or in odds and ends of military surplus chassis. These capacitors are held in high esteem by the homebrew audio fraternity which feels that, in general, paper/oil capacitors integrate musical waveforms in a sonically superior way. Don't ask me how! I can also recommend the use of polyprypelene dielectric types which I have found offer superior performance in sample and hold circuits due to the characteristics of the dielectric, and should likewise offer a low distortion signal path. At the bottom of both my list and those of the hollow state audio fraternity come the mylar dielectric types, although to be honest, I probably couldn't tell that they were being used under blind test conditions. One thing I'll say about the Vitamin Q and similar paper/oil hermetically sealed types: I've never seen one fail, even in WW II era radio equipment. Just ensure that capacitors, especially paper types, are run at a substantial voltage derating factor for longest life under torrid conditions as well as for minimizing internally generated noise.

Again, for longest life, I'd recommend sealed can types for the power supply filters and bypasses, but they are rather large. I ended up using Mallory TCG computer grade electrolytics for these applications.

Miscellaneous Construction Notes

Williamson and others have cautioned builders of amplifiers to widely separate power transformers and filter chokes from the output transformers to minimize hum coupling. I chose not to do so; the spacing between transformer end bells is nearly an inch, and the residual hum present in the complete amplifier is extremely low. All internal wiring is mil spec surplus silver plated copper with teflon insulation - not for any alleged sonic reasons, but because it's not damaged when hit with a hot soldering iron. All heater wiring was twisted up in an electric drill to cancel hum effects and installed before any other parts were wired in so it could lie next to the chassis.

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T-8040 Transmitter from page 9

am listening to Field Day on it; this is the best receiver I've used for severe QRM conditions.

Homebrew plans for the future include combining the R-8040 and T-8040 in a plywood cabinet to make a complete portable AM station for vacation use. Even with space for an antenna, phones, mic, flashlight, line cord, logbook, etc., the whole thing would only be about 16" x 9-1/2" x 8" (H x W x D) and less than 15 pounds.

After that, at Editor Wiseman's suggestion, I may look at a transceiver using battery operated tubes on a single chassis for real portable operation. We are talking of something at the 2 to 10 watt power output level, able to operate from 9 volt and flashlight batteries and go in a corner of your hamfest tote bag. This might combine versions of the R-8040 and T-8040 to give you a very low power general use portable or it might be further simplified by crystal control of both TX and RX.

(Sound of teeth again). I don't know why I listen to him.

Finally, with some changes, you could build a receiver along the lines of the R-8040 but covering all bands -- indeed, it might even be a general coverage unit. This set wouldn't be a lot more work to build than the R-8040 and in the hamband-only version would cost about the same since special order filter crystals would be eliminated. I hope someone else tackles this first (those constructors for whom serial no. 2 of a design is too tame, will find more info in the R-8040 note package) but if not, I probably won't be able to resist. **ER**

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For superior high frequency and transient response it's important to minimize the capacitance of signal paths to ground. For example, C6 and C7 are physically large can type capacitors that needed additional support beyond that of the lead wires. (They're .25 uF 1000-volt Sprague 'Chlorinols'.) I measured their capacitance from terminals to can and came up with near 100 pf, so they were epoxied to a piece of perfboard which in turn was glued to the chassis. This expedient reduced their terminal to chassis capacitance to less than 15 pF.

Surplus ceramic tube sockets were used throughout - because they look nice! Tube shields were unnecessary as evidenced by the low residual hum specs.

As is common practice, the 6.3 volt heater line is elevated to a DC voltage of about 45 via a divider from the main B+ line to minimize hum. C5, the heater signal bypass capacitor, is very important in keeping hum and noise down. Don't leave it out.

A surplus EMI filter is used at the AC line input to keep out high frequency line noise as well as to provide some degree of protection to the power supply from voltage spikes. C1-C4, across the rectifiers, are present to prevent a clicking type of transient that has been reported as audible in amplifiers using a choke input filter, as this one does. Reportedly, this transient-generated noise is created as the rectifiers switch on and off during the AC cycle, and can be generated by tube type rectifiers as well as the silicon variety.

An Amperite delay relay that operates a second, heftier relay allows the tubes to warm up prior to the application of B+. As a protective feature, I chose to use a surplus relay with a 90 VDC coil that will only operate and enable the main B+ if bias voltage is present. No bias, no B+. As it should be. **ER**

Part three next month.

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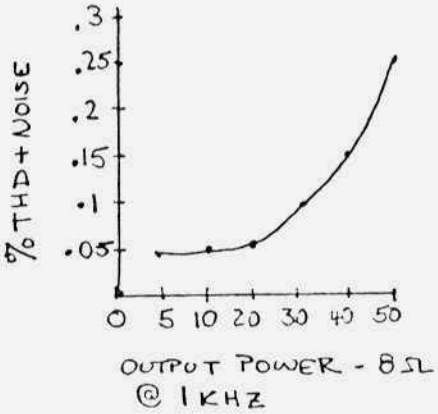


Figure 1

Performance

Ahh! The best part! Firing up the new piece of gear for the first time, running some bench checks and hauling it (grunt) into the house for those first listening tests. I played scope jockey for an evening optimizing things and charting out the performance. Some of the results are graphically shown in figures 1 and 2.

Many of the specs were better than expected. In addition to the remarkably flat response shown on the graph, the distortion specs are far, far better than any amount that could be audible, being under .1% at midband where the ear is most sensitive.

Other measured specs, not graphically shown: Hum and noise output of .0005 volts RMS, which equals a signal to noise ratio (or dynamic range) of 92 dB. Channel to channel gain matching is within 1/10 dB. When fed with a 5 kHz squarewave and driven to full power, the maximum rise and fall times are slightly less than 1.5 microseconds, an indication of the excel-

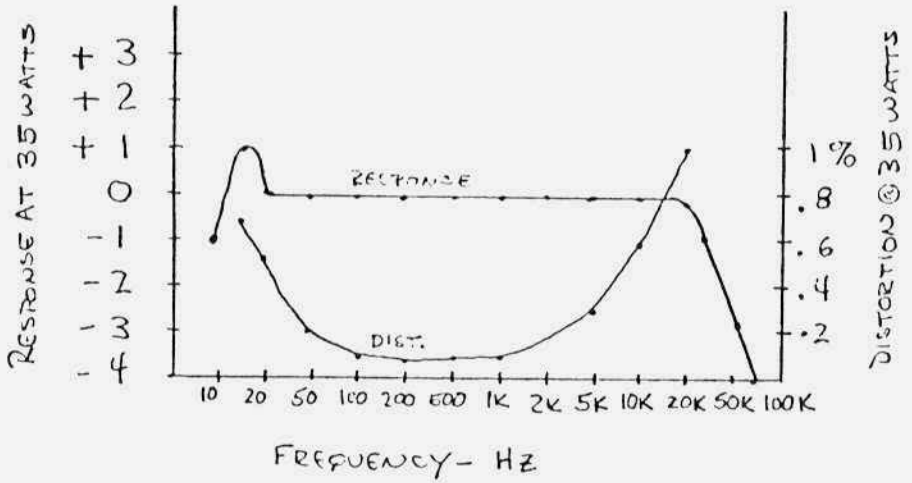
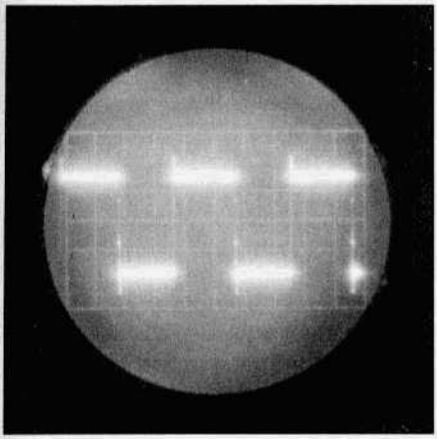
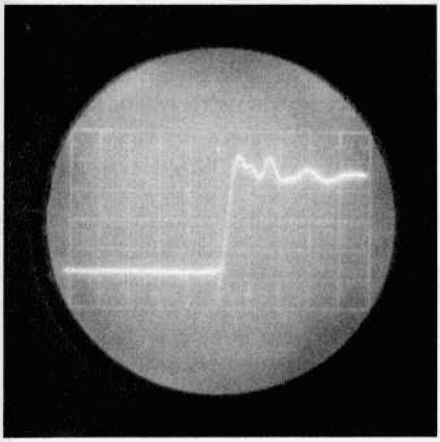


Figure 2



#1 5 kHz squarewave response. Flat tops indicate excellent power supply transient response.



#2 Expanded, delayed sweep version of above. 5 microseconds/division. Note excellent risetime of 2 uS, an indication of output transformer quality and low wiring capacitance.

lent quality of the output transformers.

So enough of the lab tests! How does it sound?

Let me start out by defining my system. My program sources for my home audio system consist of a modified mid-'50's era Knight AM-FM tuner, a CD player and an older Dual turntable using a Shure V15 type 3 cartridge. My preamp is a Hafler DH-110 of recent vintage and my speakers are a pair of mid-'70's vintage Large Advents - still a darn good on-axis loudspeaker.

I pulled the old Pioneer out of line and replaced it with the Williamson and played several CDs my wife and I were both familiar with - some contemporary, some old, including Mozart piano pieces, Sting, Paul Simon's Graceland, Benny Goodman and even Stevie Ray Vaughn. After about a half an hour, my wife's first comment was, "How'd you make it to sound so good?" And, indeed it did. The old upper midrange harshness that I found evident on some CDs was largely gone. The amp was incredibly, subjectively quiet as evidenced on the classical pieces with their wide dynamic range requirements. Perhaps the most stunning difference was the sound of percussion instruments, including drums and piano. Drums and cymbals came alive with a sound that one can only recollect from live concerts, must as certain smells bring back vivid memories. You could hear the impact of stick on drum, not just a vague thud. You can hear the sound of the hammers in a piano striking the strings, and the following tone, not just a note generated by a vibrating string. On some, but not all CDs, the presence of the playback apparatus in my living room seemed to disappear; the medium became transparent to the software. In short, we were impressed.

But why? I wasted little time in throwing my old amplifier on the same bench the new one had just departed from, hooked up the same test equipment and ran the same tests. In virtually every regard, the solid state Pioneer met or approximated the specs of the Williamson, even having somewhat better distortion at the same power levels. The only significant difference I could find was that the solid-state amp had an inferior response in the 20 kHz + supersonic range, and its 5 kHz squarewave risetime reflected this, being on the order of 25 microseconds. But, audio response in the supersonic range shouldn't matter, should it? Perhaps it does, a little bit at least.

continued next page

Or, perhaps, is the explanation for why the Williamson sounds so darn good one that enthusiasts of hollow-state electronics have known for a long time? Vacuum tubes are simply superior to transistors when it comes to amplifying analog signals. But we already knew that! Happy building!

In Case of Trouble...

This circuit can be deceiving in its simplicity. Due to the high degree of inverse feedback used, this 'simple' circuit can cause one to pull out mass quantities of hair in debugging.

This circuit, as described, will work incredibly well but I can only vouch for its success with the use of the recommended Magnequest transformer, or another that meets the original Williamson specs (again, 100 HYS minimum primary inductance, 50 mH maximum leakage inductance). Other transformers can be used, but the tradeoffs might include slightly higher distortion or lesser frequency response. A decent scope and audio generator are essential to any circuit modifications or debugging! Here's some problems you might encounter and some fixes:

1. Test the amplifier first without any inverse feedback. Leave the feedback resistor from transformer to cathode of 1st amp disconnected. If unit works reasonably OK, connect feedback. If you get a HARD oscillation, reverse the primary connections of the output transformer from tube to tube. This eliminates phase problems.

2. Low frequency oscillation below 25 Hz. This can be caused by inadequate decoupling capacitors in the plate circuits of the 1st two stages or the specs of the output transformer. A cure can be effected by reducing the amplifier's open loop low frequency response by reducing the value of the coupling capacitors between the phase splitter and 12BH7 driver. When feedback is connected, the response will flatten out.

3. High frequency oscillations. Could be anything, there's lots of gain present! Some things to try are: Add a .01 uF disc capacitor between the common cathode connection of the 12BH7 and ground. Remove the series high frequency stability network from the plate circuit of the 1st amp (the 820 pF/4.7K series network) and replace same with a 47 pF disc from grid to plate of the phase splitter. The last thing to try is the addition of a high frequency snubber network across the primary of the output transformer. This network is a series connected capacitor and power resistor connected from plate to plate of the output tubes. Good values to start with are from 500 pF to .001 uF @ 2 KV or better and about 10K, 20 watts for the resistor. Use the largest value of resistor that clears up the oscillation, 15 or 20K might also work. Normally, the resistor won't even get warm, but during high frequency testing with an audio generator, heat will be generated.

4. The above suggestions always worked where I had problems during construction of different amplifier models. However, if all else fails, increase the value of the feedback resistor (thereby reducing the feedback) to where the complete amplifier is stable. This will, of course, increase the distortion but I doubt anyone would notice. As I mentioned earlier, Theo Williamson's major discovery was that with the use of an output transformer that had exceedingly good specs, one could use enough inverse feedback to essentially eliminate any distortion products. There are tradeoffs and no free lunch!

Finally, do not exceed 500 plate volts when using the 6CA7/EL34. I recommend 475 max. If using 500 volts or better volts, I'd suggest using the 6550 instead. Good luck! ER